A Comparison of WAM and MRI on the Basis of Observed Directional Wave Spectra

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1. INTRODUCTION

To date, the first generation wave prediction model, MRI, has practical use for the design of port and harbor structures in Japan. Third generation wave prediction models, particularly the WAM model, now receive widespread practical use in other countries so it is anticipated that in the future these models may supercede the MRI model in Japan. There has been no previous examination of the applicability or the prediction accuracy of WAM from the viewpoint of practical use on the Japanese coast, hence the need for this paper.

With advances in technique of the wave observation, recently, information on the wave directional spectrum has been accumulated in addition to information on the wave height, the wave period and the wave direction. Therefore, it is considered fruitful to discuss the accuracy and applicability of the wave prediction models by comparing the predicted directional spectra and the observed directional wave spectra. As a first step in developing practical third generation wave prediction models for use in Japan, this paper compares the prediction accuracy of the WAM and MRI models based on observed directional wave data.

2. OUTLINE OF WAVE PREDICTION MODEL

Wave prediction methods are classified into the significant wave method and the spectrum method; the latter of these has recently received widespread use. The fundamental equation of the spectrum method is the energy conservation equation based on the energy input and output for the component waves of the spectrum. The time-spatial change of the wave energy spectrum is numerically computed by the equation.

In general, the change of the wave spectrum due to generation, development, propagation and dissipation is expressed by the following equation for wave energy conservation (Hasselmann ; 1960):

$$\frac{\partial E(\omega,\theta)}{\partial t} + C_g \cdot \nabla E(\omega,\theta) = S \qquad (1)$$

where ω is the angular frequency, θ is the wave direction, $E(\omega,\theta)$ is the directional wave spectrum, C_g is the group velocity of the wave component having an angular frequency ω. The first and the second terms on the left hand side show local time change of the wave spectrum and spatial change of energy flux, respectively.

S in the right hand side is called the energy source function. This term expresses the energy transfers that take place. The source function S is generally expressed as

$$S = S_{in} + S_{dis} + S_{nl} \qquad (2)$$

where S_{in} is the wind input source term, S_{dis} is the dissipation source term by wave breaking etc., and S_{nl} is the nonlinear source term expressing energy exchanges among the wave components.

Spectrum models are usually classified into three types: first, second and third generation wave prediction models, depending on the way the nonlinear source is dealt with. MRI, the first generation wave prediction model, doesn't take into account the nonlinear source term S_{nl} explicitly; however, it considers the effect implicitly as follows. MRI adopts the empirical developing term S_{in}, which is formulated based on observation data that include some of the nonlinear interaction effect indirectly. (Isozaki and Uji, 1973). On the other hand, WAM, as a third generation wave prediction model, directly estimates S_{nl} based on a theoretical study by Hasselmann (1962). Note however, that it is impossible to calculate the nonlinear interaction effect exactly since the effect requires the computation of an infinite number of combinations of four-wave resonance. WAM therefore adopts the DIA (Discrete Interaction Approximation) for the purpose of efficient computation of the nonlinear energy transfer. This is effected by replacing the integration with respect to an infinite number of combinations of four resonant waves by an integration based on the most important single combination.

3. EXAMINATION OF PREDCTION ACCURACY

In this paper, we examine the prediction accuracy of WAM by comparing the observed wave data with the results predicted by both MRI and WAM. In the following sections, we describe the characteristics of the observed wave data used in this study and the numerical conditions for wave prediction. Incidentally, the results of the wave prediction are compared with the observed wave characteristics such as the significant wave height, the significant wave period and directional wave spectrum.

3. 1 OBSERVATION DATA (IWAKI OFFSHORE DATA)

Wave data used was observed at the Iwaki offshore wave observation station (Iwaki-oki St.) constructed and maintained by the Second District Port Construction Bureau, Ministry of Transport. The Iwaki-oki St. is located at 37° 17' 49" north, 141° 27' 47" east. Water depth here is 154m, ensuring deepwater waves were observed at the station (see Figure-1). At the station, we observed the seven components of the wave quantities using four step-type wave gauges and a 2D-current meter with a pressure-type wave gauge. Observations were carried out for 20 minutes every 2 hours with a sampling interval of 0.5 second. We used the zero-up crossing method to compute the significant wave statistics and to estimate the directional wave spectrum by the Extended Maximum Entropy Principle Method (EMEP) (Hashimoto et al. ; 1993).

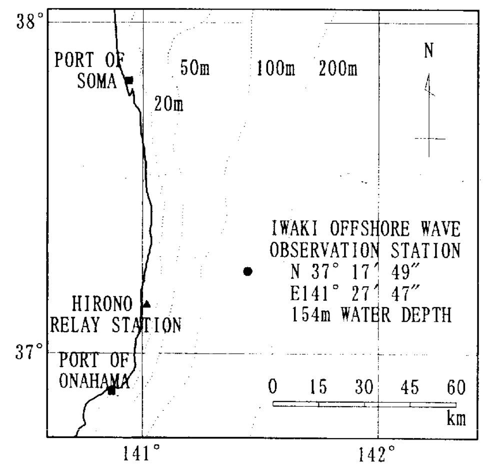


Figure-1 Location of the Iwaki-oki wave observation station

3. 2 WIND DATA (ECMWF DATA)

The wave prediction accuracy strongly depends on the accuracy of both the input wind data and the wave model. In wave generation and development waves grow by gaining energy from the wind so the prediction accuracy of a sophisticated wave model cannot be improved beyond the accuracy of the input wind data. Therefore, it is necessary to assess the accuracy of the input wind data before using wave prediction models.

To investigate the accuracy of the observed wind data, we verified the accuracy of the ECMWF wind data with the observed wind data measured by Japan Meteorological Agency buoys from 1993 to 1997 (Figure-2). The Japan Meteorological Agency wind data is observed at a height of 7.5m above the sea surface; however, the ECMWF wind data is computed at the 10m above the sea, so the observed wind data should be adjusted. Here, we adjusted the buoy data by applying the 1/7-power low as follows:

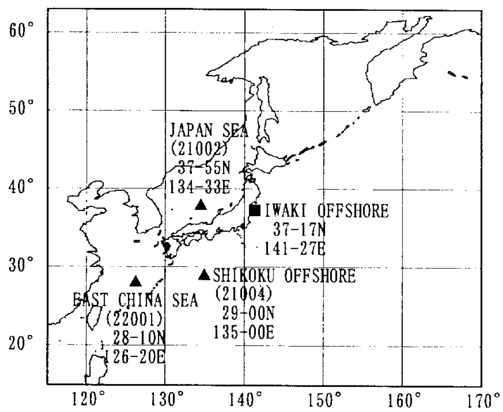


Figure-2 Wind observation location

$$U_h = U_0 (h/h_0)^{1/7} \tag{3}$$

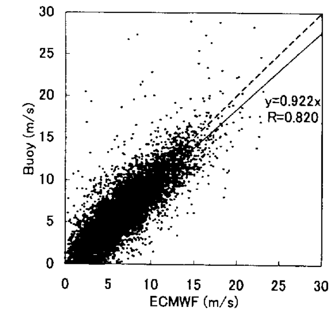
where U_h and U_0 is the wind speed at the height of h and h_0 on the sea, respectively.

We calculated the correlation coefficient between the ECMWF wind data and wind data from the buoys, adjusted using Equation (3). **Figure-3** shows the correlation of the data measured at the Shikoku-offshore buoy. Though some biases are seen in the wind speed, the correlation coefficient is 0.82 and is considered to be of acceptable accuracy. Furthermore, the correlation of the wind direction is also acceptable though wind direction bias is a little larger than that of the wind speed. Similar results are obtained at the other two points, i.e., the correlation coefficient of wind speed ranges from 0.82 to 0.85, and the correlation coefficient of wind direction ranges from 0.70 to 0.81.

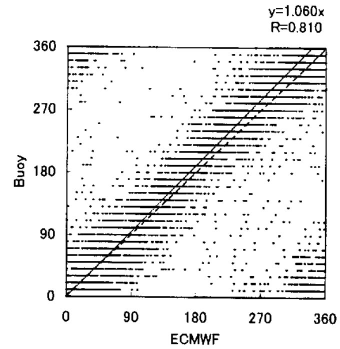
From this assessment, we may conclude that the ECMWF wind data is reliable enough to be used as an input wind data for the wave prediction.

3. 3 PREDICTION CONDITIONS

The area for wave prediction was performed is from 15° to 63° in latitude and from 115° to 170° in longitude to prevent the results of the wave prediction at Iwaki-offshore station from being influenced by the boundary conditions. (see Figure-2). The wave prediction was carried out under deepwater conditions



(a) Wind speed



(b) Wind direction

Figure-3 Correlation of wind speed and wind direction (Shikoku-offshore)

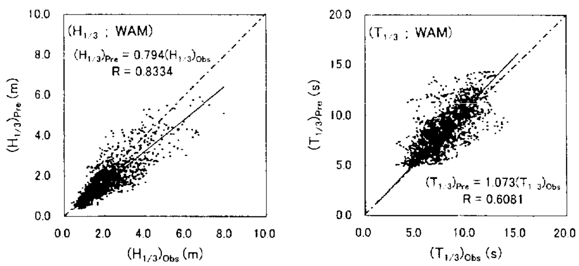
with the wave direction discretized into 16 segments for both MRI and WAM.

Cases examined were selected to contain various weather conditions and spectral characteristics under severe sea conditions at the Iwaki-offshore station in 1993, and compared the predicted results and the observed data. We computed the sea conditions for two weeks in total including times when the maximum significant wave height occurred.

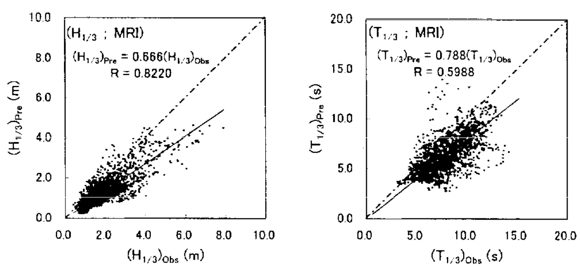
4. RESULTS

4. 1 EXAMINATION ON SIGNIFICANT WAVE STATISTICS

Figure-4 shows a comparison of the predicted significant wave height and period with the observation data for all cases examined. The prediction results for four days at the beginning are excluded as these may be influenced by the initial conditions. **Figure-4** shows that though both MRI and WAM underestimate the significant wave height for high wave conditions, MRI tends to underestimate high waves much more than WAM. For the significant wave period, WAM predictions show good agreement with the observed data; however, MRI again underestimates the wave period. From the results of the examinations, the prediction accuracy of WAM is better than that of MRI. Nevertheless, both models were found to underestimate the wave height when predictions were compared with the observation data.



(a) WAM



(b) MRI

Figure-4 Correlation of significant wave height and period

4. 2 EXAMINATION ON DIRECTIONAL WAVE SPECTRUM

Figure-5 shows an example of the time series of ECMWF wind data, and the significant wave height and the period estimated by WAM and MRI. This example is for the case where a low-pressure generated in the northern area of the Japan Sea runs through the north of the Honshyu toward the Okhotsk sea. The observed significant wave height, period and mean wave direction are also shown in **Figure-5**. **Figure-6** shows the time series of the directional wave spectrum for the same case as **Figure-5**. From these two figures, it is seen that the directional wave spectrum with two predominant peaks changes to a single peak spectrum during the development process. By contrast, the single peak spectrum changes to a multi peak spectrum during the process of decay. As seen in these figures, MRI does not always reproduce the pattern of change of the directional wave spectrum; however, WAM can reproduce the change in pattern properly. The difference in the response to the spectrum changes in WAM and MRI is considered to be due to the rapid change of the wind field in the decay stage (see **Figure-5**). When the wind field changes rapidly, WAM is considered to be superior to MRI as WAM's response is more sensitive to the change of wind field than that of MRI.

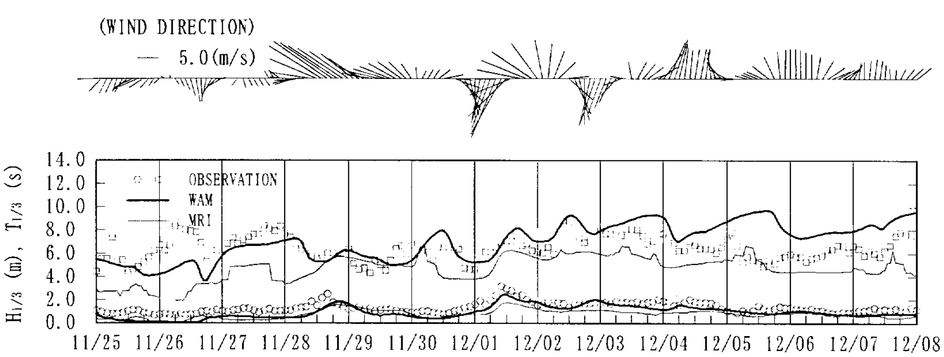
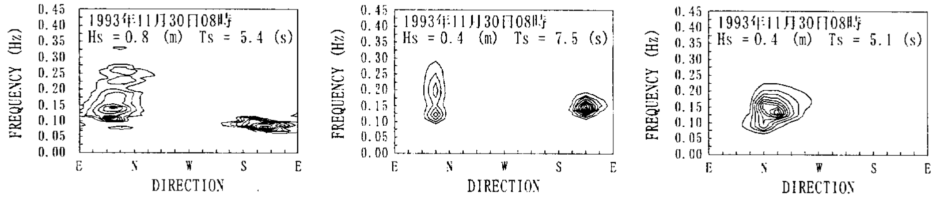
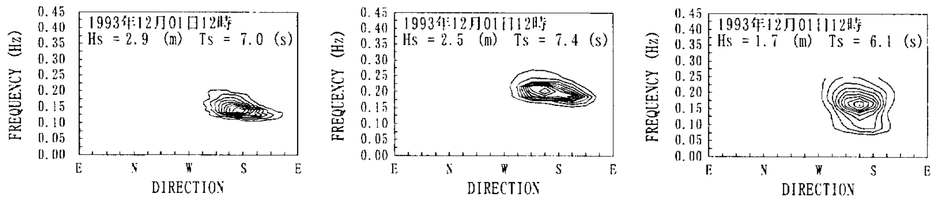


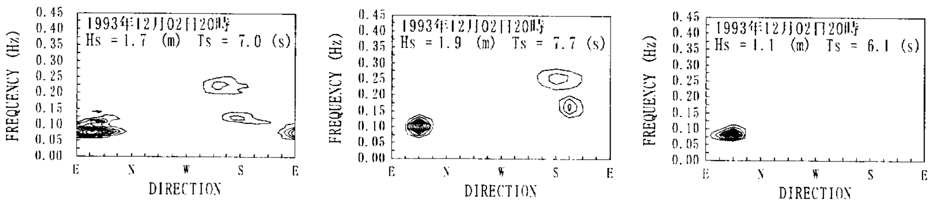
Figure-5 Time series of significant wave statistics and ECMWF wind data



(a) Development Term



(b) Peak Term



(c) Damping Term

Figure-6 Comparison of directional wave spectra（Left：Observation, Center：WAM, Right：MRI）

4. 3 EXAMINATION ON WIND WAVE AND SWELL

Figure-7 shows an example of the wave prediction results from March 9 to 17 in 1993. This case shows a bad weather condition where a developing low-pressure extends offshore of the Kanto area from Shikoku to the northeast of the Pacific Ocean side of Japan. For this case, both WAM and MRI can be seen to underestimate the wave height. The difference in wave height between the observation and prediction is upwards of approximately 2m around the time the peak wave height occurred at 0:00, March 9.

Figure-8 shows the time series of the wind wave and swell components separately from the data of **Figure-7**. Judging from **Figure-7**, the reason for the underestimated wave heights around when the peak wave height occurred is apparently due to underestimation of the swell component.

In MRI, it is assumed that the amount of energy input from the wind to the wave is balanced by the amount of dissipation due to wave breaking. This would lead the shape of the wave spectrum to approach the form of an equilibrium spectrum. The wave energy dissipation term is formulated by equation (4).

$$S_{dis} = (A + B \cdot S)(S / S_{\infty})^2 \qquad (4)$$

where S_{∞} is the equilibrium spectrum given by PM spectrum.

As explained above, since MRI prediction approach the equilibrium spectrum defined by the PM spectrum, it is difficult for MRI to express spectra with sharp spectral peaks, such as the spectrum of swell. On the other hand, WAM also contains many parameters, some of which are used to control the shape of the spectrum. For example, the “limiter” used to limit the increment of wave energy input in a specified period, which may prevent the waves from developing into a sharp shaped spectrum. It is thought that these reasons, are why both MRI and WAM underestimate the swell component.

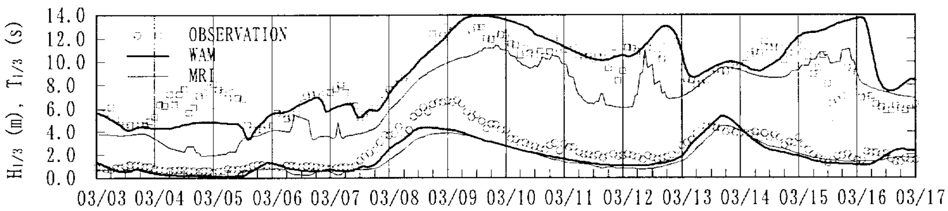
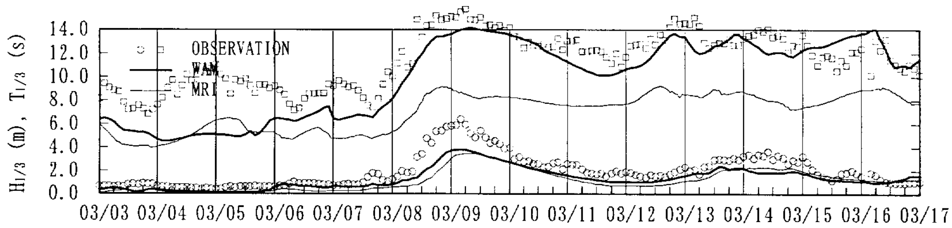
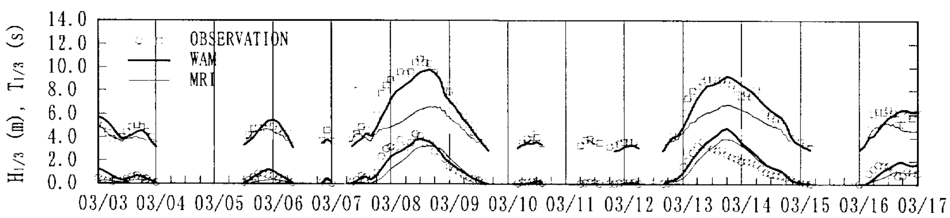


Figure-7 Time series of significant wave statistics (1993/3/3～3/17)



(a) Swell



(b) Wind Wave

Figure-8 Time series of wind wave and swell component

5. CONCLUSIONS

In summing up the results of this comparative study of WAM, MRI and observation data described above, the following are the major conclusions.

1. The wave characteristics predicted by WAM are closer to the observation data than those predicted by MRI.
2. WAM can reproduce properly the change in the directional wave spectra measured in the field, not only for the single peak spectrum but also for the multi peak spectrum.

From this study, we can conclude that the prediction accuracy of WAM is higher than that of MRI for all wave characteristics, that is, significant wave height, period and directional spectra. However, WAM tends to underestimate wave height for severe sea conditions as it contains insufficient evaluation of swell component. Further improvements are required to WAM for it to be used for practical purposes in Japan.

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REFERENCES

Hashimoto, N., T. Nagai, T. Asai and K. Sugawara (1993) : Extension of Maximum Entropy Principle Method (MEP) for Estimating Directional Ocean Wave Spectrum, Rept. of Port and Harbour Res. Inst., Vol. 32, No.1.

Hasselmann, K. (1960) : Grundgleichungen der Seegangsvoraussage , Schiffstechnik , 7 , pp.191-195.

Hasselmann, K. (1962) : On the non-linear energy transfer in a gravity-wave spectrum, Part1, General theory, J. Fluid Mech., 12, pp.481-500.

Isozaki, I. and T. Uji (1973) : Numerical Prediction of Ocean Wind Waves, Papers in Meteorology and Geophysics, Vol.24, No.2, pp.207-231.

Komen,G.J. and 5 authors (1994) : Dynamics and Modelling of Ocean Waves , Cambridge University press.

The WAMDI Group (1988) : The WAM model-A third generation ocean wave prediction model, J. Phys. Oceanogr., 18, pp.1775-1810.